<International Research Center for Elements Science>Photonic Elements Science

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– Photonic Elements Science –

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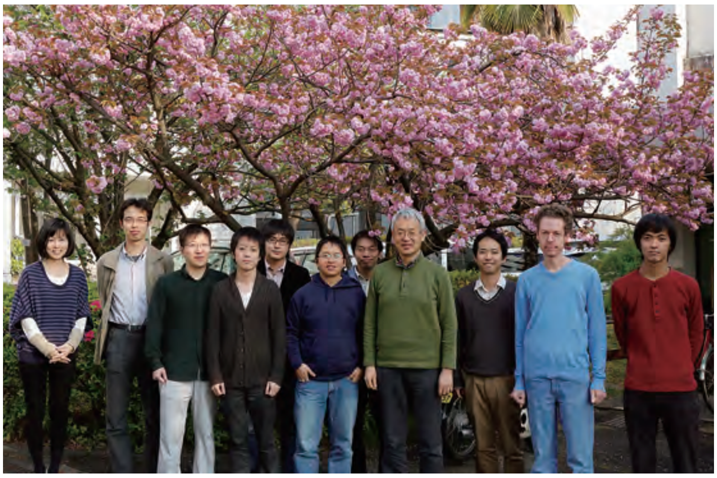
Scope of Research

Our research interest is to understand optical and quantum properties of nanometer-structured materials and to establish opto-nanoscience for creation of innovative functional materials. Optical properties of semiconductor quantum nanostructures and strongly-correlated electron systems in low-dimensional materials are studied by means of space- and time-resolved laser spectroscopy. The main subjects are as follows: (1) Investigation of optical properties of single nanostructures through the development of high-resolution optical microscope, (2) Development of nanoparticle assemblies with new optical functionalities, and (3) Ultrafast optical spectroscopy of excited states of semiconductor nanostructures.

KEYWORDS

Femtosecond Laser Spectroscopy
Carbon Nanotubes
Semiconductor Nanoparticles
Transition Metal Oxides
Semiconductor Nanostructures



Selected Publications

Yamada,Y.; Sato, H. K.; Hikita, Y.; Hwang, H. Y.; Kanemitsu, Y., Measurement of the Femtosecond Optical Absorption of $LaAlO_3/SrTiO_3$ Heterostructures: Evidence for an Extremely Slow Electron Relaxation at the Interface, *Phys. Rev. Lett.*, **111,** [047403-1]-[047403-5] (2013).

Matsunaga, R.; Matsuda, K.; Kanemitsu, Y., Observation of Charged Excitons in Hole-doped Carbon Nanotubes Using Photoluminescence and Absorption Spectroscopy, *Phys. Rev. Lett.*, **106,** [037404-1]-[037404-4] (2011).

Yamada, Y.; Yasuda, H.; Tayagaki, T.; Kanemitsu, Y., Temperature Dependence of Photoluminescence Spectra of Undoped and Electron-doped $SrTiO_3$: Crossover from Auger Recombination to Single-carrier Trapping, *Phys. Rev. Lett.*, **102,** [247401-1]-[247401-4] (2009).

Matsunaga, R.; Matsuda, K.; Kanemitsu, Y., Evidence for Dark Excitons in a Single Carbon Nanotube Due to the Aharonov-Bohm Effect, *Phys. Rev. Lett.*, **101,** [147404-1]-[147404-4] (2008).

Hosoki, K.; Tayagaki, T.; Yamamoto, S.; Matsuda, K.; Kanemitsu, Y., Direct and Stepwise Energy Transfer from Excitons to Plasmons in Close-packed Metal and Semiconductor Nanoparticle Monolayer Films, *Phys. Rev. Lett.*, **100,** [207404-1]-[207404-4] (2008).

Topics

Auger Process in Disklike InAs Quantum Structures

Fabrication and characterization of semiconductor nanostructures have been extensively studied due to interest both in the fundamental physics and potential applications in optoelectronic devices. We studied the mechanisms of upconverted photocurrent in InAs quantum structures embedded in $Al_xGa_{1-x}As$ using simultaneous measurements of photoluminescence and photocurrent spectra. Efficient upconversion was verified in samples with and without quantum dots. The dominant upconversion process from low temperatures to room temperature was found to occur through an Auger process in disklike InAs quantum structures. The results suggest the importance of shallow energy levels, which enable upconversion and efficient carrier extraction through multiparticle interactions. The disklike structure was concluded to be a suitable intermediate-band structure in terms of the energy conversion efficiency.

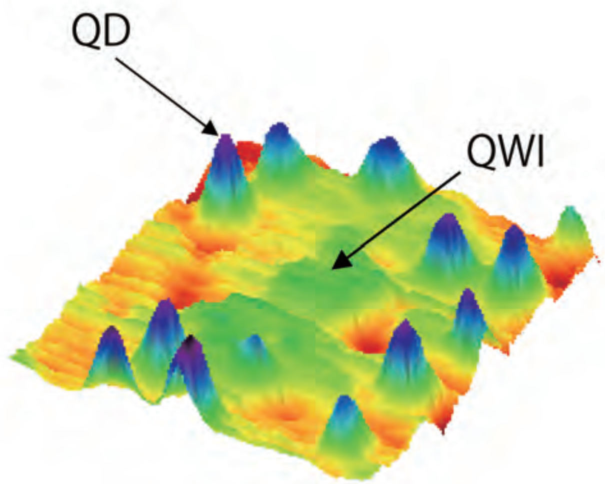


Figure 1. 3D AFM image with quantum dots (QDs) and a quantum well island (QWI) on the wetting layer of an InAs/AlGaAs layer without capping.

Charged Exciton Formation and Recombination Dynamics in Hole-doped Carbon Nanotubes

Carbon nanotubes are one of the excellent materials for studying the optical properties of excitons, because of their unique band structures and large exciton binding energies. We studied the trion (charged exciton) formation and recombination dynamics in hole-doped (7,5) single-walled carbon nanotubes (SWCNTs) by performing femtosecond transient absorption spectroscopy. The doping of SWCNTs with holes leads to a fast decay component from an exciton to a trion, and the trion decays with a lifetime of a few picoseconds. The experimental results can be explained by a quantized model accounting for the dark exciton and trion states and the hole number distribution in a SWCNT. Our findings show that the optical responses of SWCNTs can be manipulated by doping of SWCNTs with a small number of holes.

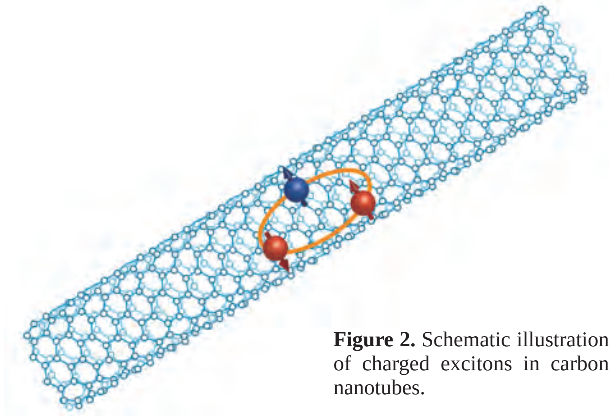


Figure 2. Schematic illustration of charged excitons in carbon nanotubes.

Current–voltage Characteristics in Ge/Si Quantum Dot Solar Cells

Quantum dots (QDs) have attracted attention because of their interesting physical properties and potential applications in optoelectronic devices such as light emitters and solar cells. In QDs, physical processes of generation, relaxation, and recombination of carriers are determined by their nanostructures and differ from those in bulk crystals. We report studies of current–voltage characteristics in Ge/Si QD solar cells in the temperature range from 100 to 300 K. We show that even though open-circuit voltage (V_{oc}) decreases with increasing temperature, it depends on the nominal Ge thickness, indicating that V_{oc} reduction is primarily caused by a decrease in the bandgap energy of the cell. From photoluminescence decay measurements, we found that rapid carrier extraction from QDs occurred in the solar cells; this process eliminates the quasi-Fermi energy splitting between the QDs and the host semiconductor and causes V_{oc} reduction in QD solar cells.

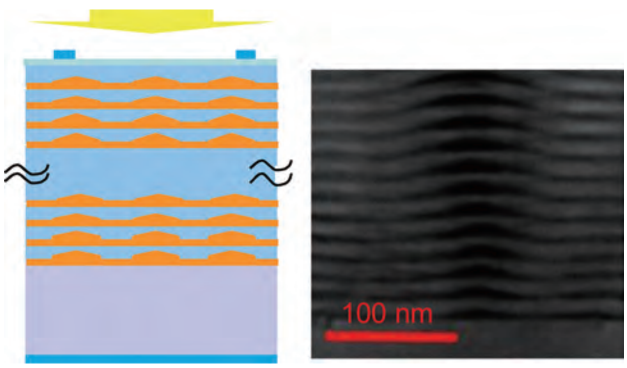


Figure 3. Schematic illustration of Ge/Si QD solar cells (left). TEM image of Ge QD array (right).